<table>
<tr><td colspan="3">REPORT DOCUMENTATION PAGE</td><td>Form Approved
OMB No. 074-0188</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td>1. AGENCY USE ONLY
(Leave blank)</td><td>2. REPORT DATE
Mar 26, 2012</td><td colspan="2">3. REPORT TYPE AND DATES COVERED
Final Report: 1/15/09 – 5/14/11</td></tr>
<tr><td colspan="3">4. TITLE AND SUBTITLE
(Nanosat FY09): SpaceBuoy: A University Nanosat Space Weather Mission (II) Solicitation Title: University Nanosat Program</td><td rowspan="2">5. FUNDING NUMBERS

Award Number: FA9550-09-1-0076</td></tr>
<tr><td colspan="3">6. AUTHOR(S)
Prof. David M. Klumpar</td></tr>
<tr><td colspan="3">7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Montana State University
Department of Physics, EPS 264
Montana State University
P.O. Box 173840
Bozeman, MT 59717
Grants and Contracts
Montana State University
103 Montana Hall
Bozeman, MT 59717</td><td>8. PERFORMING ORGANIZATION REPORT NUMBER</td></tr>
<tr><td colspan="3">9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
AFOSR, 875 N RANDOLPH ST
ARLINGTON, VA 22203</td><td>10. SPONSORING / MONITORING AGENCY REPORT NUMBER

AFRL-OSR-VA-TR-2012-1145</td></tr>
<tr><td colspan="4">11. SUPPLEMENTARY NOTES</td></tr>
<tr><td colspan="3">12a. DISTRIBUTION / AVAILABILITY STATEMENT
Distribution A: APPROVED FOR PUBLIC RELEASE</td><td>12b. DISTRIBUTION CODE</td></tr>
<tr><td colspan="4">13. ABSTRACT (Maximum 200 Words)
Montana State University students, faculty mentors, and collaborators, designed a microsatellite under the AFOSR/AFRL/AIAA University Nanosatellite Program VI. Major motivation for the project was to promote the educational development of students as engineers and scientists in space hardware and space systems engineering. Approximately 50 students participated in the project. The satellite will accomplish substantive scientific, engineering, and technological objectives including the demonstration of a novel payload consisting of two instruments designed by our NRL and AFRL collaborators; demonstration of near-real-time data delivery to users of the GAIM model for ionospheric forecasting; and further application of consumer and COTS devices in the space environment. During the grant period the SpaceBuoy satellite moved through initial design, design freeze, engineering design, prototyping, subsystem testing, and well into hardware fabrication. Strict adherence to proper design methodologies was enforced; internal and external design reviews took place; and a configuration management system, previously developed in our Montana Space Grant sponsored Explorer-1 PRIME program, was improved using a local Wikimedia electronic system, ensuring adequate documentation of the design and tracking of changes following subsystem design freeze. This final report updates progress subsequent to the prior progress report incorporated as an appendix.</td></tr>
<tr><td colspan="3" rowspan="2">14. SUBJECT TERMS
Nanosatellites, Space Weather</td><td>15. NUMBER OF PAGES
7 + cover</td></tr>
<tr><td>16. PRICE CODE</td></tr>
<tr><td>17. SECURITY CLASSIFICATION OF REPORT
Uncl.</td><td>18. SECURITY CLASSIFICATION OF THIS PAGE
Uncl.</td><td>19. SECURITY CLASSIFICATION OF ABSTRACT
Uncl.</td><td>20. LIMITATION OF ABSTRACT</td></tr>
</table>

NSN 7540-01-280-5500 **Standard Form 298 (Rev. 2-89)**

SpaceBuoy: A University Nanosat Space Weather Mission
Solicitation Title: University Nanosat Program

FINAL REPORT

Award Number: FA9550-09-1-0076

26 March, 2012

This final report includes, in the Appendix, a prior progress report covering the period from January 15, 2009 – January 14, 2010 submitted on March 18, 2010. The period of performance for the entire grant covers the period from January 14, 2009 to May 14, 2011. The following section describes grant activities from January 15, 2010 through the end of the grant period on May 14, 2011. This entire package constitutes the Final Project Report.

Summary
Montana State University students, faculty mentors, and our collaborators at NRL and AFRL, designed a microsatellite under the AFOSR/AFRL/AIAA University Nanosatellite Program VI. A major motivation for the project was to promote the educational development of students as engineers and scientists in space hardware and space systems engineering. Approximately 50 undergraduate and graduate students participated in the project. Additionally, the satellite was designed to accomplish substantive scientific, engineering, and technological objectives including the demonstration of a novel payload consisting of two instruments designed by our NRL and AFRL collaborators; demonstration of near-real-time data delivery (within 2 hours of being taken) to users of the GAIM model for ionospheric forecasting; and further application of consumer and COTS devices in the space environment. During the reporting period the SpaceBuoy satellite moved through initial design, design freeze, engineering design, prototyping, subsystem testing, and well into hardware fabrication. Subsequent to the January 2011 program "Flight Competition Review", the satellite was not selected by AFRL for flight development under the University Nanosatellite Program VI. Processes and procedures adopted by the Montana State University design team included strict adherence to proper design methodologies; regular internal and external design reviews; and a configuration management system, previously developed in our Montana Space Grant sponsored Explorer-1 PRIME program, was improved using a local Wikimedia electronic system, ensuring adequate documentation of the design and tracking of changes following subsystem design freeze. This portion of the final report updates progress subsequent to January 14, 2010 and summarizes the final status at the end of the grant. The prior progress report that is incorporated herein as Appendix 1 details activities from the beginning of the grant through January 14, 2010.

Status of the Effort and Accomplishments

Flight Review January 17, 2011
The SpaceBuoy development team prepared and participated in the AFOSR/AFRL/AIAA flight competition review held in Albuquerque, NM on January 17, 2011 for the University Nanosat program. A total of three students and one faculty advisor made the trip to Albuquerque to present the SpaceBuoy satellite mission to the review panel. The SpaceBuoy presentation focused on our successes and flyability as well as our well thought out, well documented mission. SpaceBuoy was not chosen for continuation in that venue; however, we submitted a proposal for the University Nanosatellite Program VII and were accepted for participation, so we are continuing the development of the SpaceBuoy mission with our current resources and student team.

Continued Fabrication

In the interval between January 14, 2010 and January 16, 2011 the SpaceBuoy student team continued fabrication of hardware to get ready for the January 2011 flight review and for use in the eventual completion of the satellite. At the time of the Flight Competition Review (FCR) a complete flight prototype spacecraft structure had been built and integrated together and selected subsystems had been developed. The Nickel-Cadmium battery package had been entirely designed and built in full compliance with Nanosat Program safety requirements. The storage and deployment system for the communications and payload antennas had been designed, and testing was anticipated within several months. Power conditioning boards including DC-DC converters and the power regulation system had been designed, and prototype boards had been built, tested, and revised based on test results. A COTS microprocessor board had been selected, purchased, and integrated into the flatsat system and was used extensively for software development and testing between the subsystems. The Langmuir Probe had been prototyped and tested at a functional level separately from the spacecraft's flatsat. At the time of the FCR, further work remained on the attitude determination and control electronics, although considerable progress had been made on the hardware design and requirements definition, as well as on preliminary software algorithms. RF transceivers had been purchased and were undergoing testing although some issues remained.

The structural design was developed entirely by students at Montana State University using design heritage from MSU's previous Maia Nanosatellite (UNP-3) and previous SpaceBuoy (UNP-5) design. The spacecraft structure was designed to accommodate a reasonable amount of adaptability to other missions that might require a larger (or a smaller) spacecraft. This modular flexibility easily allowed for adaptation for the NRL CITRIS payload as well as the AFRL Planar Langmuir Probe payload, as well as to meet particular mission requirements by the use of a modular stacking central electronics bay that houses batteries, and both payload and spacecraft electronic subsystems. To date, the prototype structural bus is complete and prototype systems exist for command and data handling (CDH), electrical power system (EPS), and communications systems. These systems continue to move forward toward a completed overall system. The systems are currently moving toward prototype system integration in a "flatsat" configuration.

The SpaceBuoy satellite is shown in Figure 1 during an integration test with the Planetary Systems LightBand deployer system. The satellite integrated seamlessly to the Lightband during this test and no issues were uncovered.

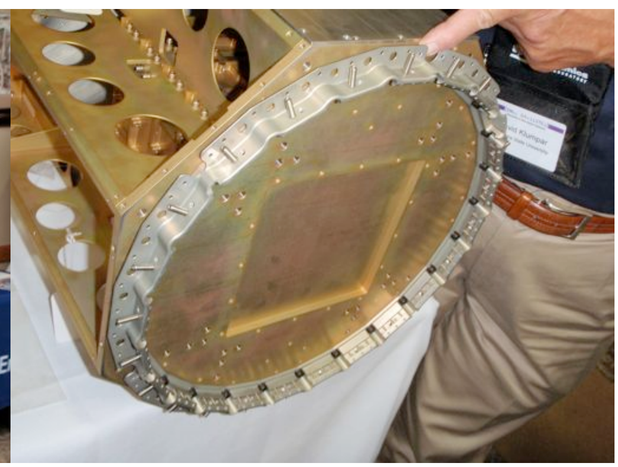

Figure 1 SpaceBuoy Satellite integration test with Planetary Systems Inc.'s Lightband. A Planetary Systems design engineer was present (blue shirt) for the entire process. Also pictured are students Scott Kratochvil (left) and Dan Schwendtner.

Figure 2 A close up view of the integrated Lightband upper adapter ring.

Program's lasting impact on the aerospace industry

The students on the SpaceBuoy team have begun to graduate and move into aerospace jobs. We consider this to be a major strength of our program, particularly given that Montana institutions are not often thought of as suppliers of aerospace talent. Program students have left Montana State University for jobs with NavSea, Orbital Sciences, Boeing, Tethers Unlimited, MicroSat Systems, United Launch Alliance, SpaceX, Sypes Canyon Communications, and Bridger Photonics, while others have chosen to continue their education in graduate school. Many of these students have proven to be capable and valuable employees at their respective companies, or are completing their graduate programs while they continue to work in space hardware programs at MSU or other schools.

Program’s lasting impact on Montana State University

The University Nanosat program’s lasting impact on Montana State University has been to develop a more professional setting sensitive to review and quality assurance issues. Future and new missions, such as Explorer 1 Prime (http://ssel.montana.edu/e1p/) and FIREBIRD (http://ssel.montana.edu/firebird/), have benefited from the structure taught by the University Nanosat Program. These lessons will be long lasting and yield major improvements in the quality of the education and workmanship from Montana State University as we continuously work with the University Nanosat Program coordinators.

Participants and Collaborators

The Montana State University's Space Science and Engineering Laboratory (SSEL), directed by Dr Klumpar, is an interdisciplinary laboratory headquartered in the Physics Department at Montana State University, with close ties to the Electrical and Computer Engineering (ECE) and Mechanical and Industrial Engineering (M&IE) Departments at MSU. Ongoing projects with SSEL include The Multi Order Slitless EUV Spectrograph, a NASA supported sounding rocket that launched from White Sands in February 2006 to measure solar emissions in the He-304 line. Our very active (more than 30 flights in four years) high altitude balloon project provides rapid turn-around flight experiences for beginning engineering and science students. SSEL has experience in leading student teams in the development for flight of miniature satellites. The Montana EaRth Orbiting Pico-Explorer (MEROPE), a 1 kg satellite, was under development for spaceflight in the SSEL for 36-months and was launched on the Dnepr Booster rocket from the Baikonur Cosmodrome on July 27, 2006 which unfortunately failed to reach orbit. Another SSEL program, Explorer-1 PRIME Unit 1 was also built by students in the SSEL and delivered for a launch on an Orbital Sciences Corpration Taurus Rocket. This satellite also failed to reach orbit, along with NASA’s Glory satellite, due to a launch contingency with the rocket. Both of these projects received primary support from the MSGC. The SpaceBuoy satellite under development from this program has increased the knowledge of the lab greatly in a structured and mentored program.

The Maia nanosatellite (UNP-3) followed naturally from the MEROPE program in many ways. It built upon the experiences gained from the past program and extended our management protocols while presenting a significantly greater engineering challenge. Student involvement in all aspects of the program, including project management, tracking and reporting as well as engineering, design, fabrication, and test have been a key element of our program and were greatly enhanced in the Maia project. Development challenges were faced and met with MEROPE. A brief comparison is included in Table 1. Those that were successful have been reapplied to Maia and lessons learned from Maia are being incorporated in our newest projects. For example, the satellite structure minimized design effort and machining set-up effort by utilizing a single common sidewall that was used for all four-side panels. One design and one machine set-up allows a CNC mill to build them almost automatically. Lessons learned from components that did not work so well will motivate us to look for improved solutions. As an example, early in the MEROPE design process we settled on a FIFO memory chip to store on-orbit data. This device has been replaced in the Maia design with RAM which allows significantly more flexibility. Maia construction, integration, and testing is providing new engineering challenges, which are being met with the same determination and insight as those in the design phase but with more experience.

With Maia as our first experience building a Nanosatellite, the lessons learned in that program were readily applied to our University Nanosatellite V and IV satellite, SpaceBuoy where much design heritage from Maia was leveraged along with the many lessons learned. Although the science mission changed significantly, the overall structural and electronics bus remained nearly the same in most respects. Because of different mission requirements that stem from the SpaceBuoy’s specific payload, some changes were necessary to accommodate the CITRIS payload and the two Langmuir Probes to include changes to the structural “wings” of the spacecraft to accommodate CITRIS, a reduction in number of available modular component boxes, reduction in complexity of the attitude determination and control system, and several additional/different voltage regulators. Additionally, SpaceBuoy utilizes an antenna design from our NRL collaborators that allows sharing of the antennas between the CITRIS instrument and the spacecraft communications subsystem.

	MEROPE (past project)	Maia (previous project)	Capability Extension/Enhancement or challenge for SpaceBuoy
Project management			
	Student led	Student led	
Major Reviews	PDR, CDR held internally	PDR, CDR, external participants	Formalize review process, involve external experts
Reporting	Internal	Internal and external	Formalize review process
Team meetings	Weekly	Weekly	Document meetings
Documentation	Subsystem Notebooks and web	Formalized documentation system	Formalized reporting procedures
Engineering			
Power system		5 v bus, commercial	
Attitude Control	Passive magnetic	Active magnetic	Develop capability to control spin axis, spin rate
Magnetometer	None	3-axis	For attitude knowledge and control
Science			
Sensor System	Geiger counter	Solid State Silicon device	Particle discrimination and energy discrimination
Technology Demonstrations			
Batteries	Li-Ion and NiMH	NiCad	Use the safe stable technology
Deployables	None	Solar wing deployed by Elastic Memory Composite Hinge	Adds engineering complexity and power
Sensors	None	Reduced energy threshold radiation sensors	Complicated design and implementation
GNC Sensors	None	Miniature low power magnetoresistive three axis magnetometer	To qualify for space flight newly developed sensor, and provide software control challenges

Table 1. Relationship of SpaceBuoy project to previous programs (MEROPE & Maia)).

Our collaborators at the NRL agreed very early in the program that a nanosatellite would be an ideal sized spacecraft for their instrument and agreed to provide MSU with a flight unit should we win the competition. Our goal was then to design a spacecraft that capable of operating their CITRIS instrument on orbit. To date, all of the necessary subsystems have been developed to support this instrument, including attitude determination and control, command and data handling, and structure, as well as the ground station capabilities necessary to process the data.

The Planar Langmuir Probe instrument is a variation of a design that our AFRL collaborators have flown successfully many times. They provided us with a schematic of the log amplifier circuit and a drawing set of the probe head and housing. MSU students took these designs and applied them for use with the SpaceBuoy mission. As with the CITRIS instrument, all necessary subsystems have been developed to a prototype stage to support this instrument on orbit.

Student Involvement

A primary goal of the Space Science and Engineering Laboratory is to educate students with the technical knowledge necessary to succeed in an aerospace career by immersing them in hands-on satellite projects. To this end, students fill all subsystem leadership roles while faculty at Montana State University mentor design decisions. Designs and trade-off decisions were made by students on the project, giving them an intimate view of satellite construction from conception, to launch, to on-orbit operations.

Students new to the lab, or to satellite construction in general, are taken in as unpaid interns and assigned to tasks that help them to understand one aspect of the satellite more thoroughly. Some assignments that have been performed or are planned include power scheme design, mechanical ground support equipment design, and antenna deployment design. Once the student has advanced technically, they are moved to a position within a satellite subsystem according to their abilities and interests.

This system of training new students offers several advantages. First of all, the students perform much better with satellite construction after they have a deeper understanding of the limitations and design theories involved therein. Second, they can contribute to the success of the lab and future missions with the completion of the training task to which they are assigned, contributing to their feeling of “ownership” in the project, and in turn increasing student retention. This procedure has been extremely successful for the four years that the SpaceBuoy program as indicated by the fact that over 100 students, coming from all different majors and interests, have worked in the lab. During summer 2009 (and again during summer 2010) a crew of ~10 students worked on the satellite as their summer project. Physics, engineering, and math students have contributed to the satellite, and art and business students have found a place on the team as well. Upon graduation students trained in the Space Science and Engineering Laboratory have found employment and internships with prestigious institutions and companies such as NASA, Los Alamos National Laboratory, Tethers Unlimited, MicroSat Systems, Jackson & Tull, and Orbital Sciences Corporation. SSEL will continue to strive to interest and train students of all backgrounds in space science and the aerospace industry.

Project Management

One major element of any mission is project management. This presents extra difficulties in a university setting where there are distractions not present in a government or industry setting. These distractions include classes, outside internships, and other extracurricular activities. To successfully manage students to achieve an overall unified goal is a challenge, but a rewarding one.

Completing a satellite and meeting a mandated deadline with primarily student labor is a challenge and requires careful planning and project management if it is to be accomplished. With the SpaceBuoy final design taking form the students were split into subsystem teams according to their interests and abilities. Subsystem teams handle the details of individual subsystems aboard the satellite and in support of it. They include power, payload, structure and attitude control, thermal control, communications, ground support equipment, computer hardware and software, and business and public outreach. Each team manages the intricacies of their system while working closely with other teams and reporting to the Project Manager. An organizational chart of the management structure is shown in Figure 3 below.

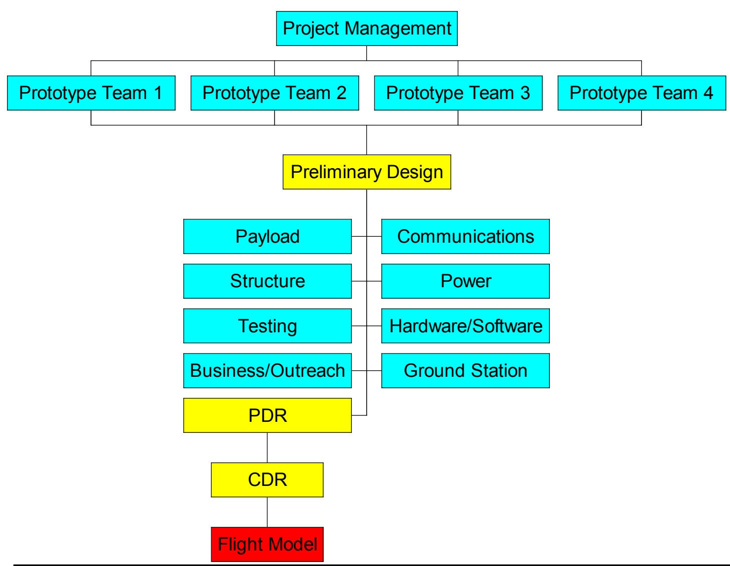

Figure 3: Project management scheme. Prior to Prelimimary Design Concept four teams independently developed prototype concepts. Following adoption of a concept at Preliminary Design eight subsystem teams were formed to design, fabricate and test the satellite.

Management and Subsystem lead positions are reserved mainly for graduate students and veterans of SSEL projects. Placing graduate students in charge has proven to be vital in maintaining continuity and efficiency in a project of this magnitude. Graduate students have a lighter course load and are obliged to do research projects; therefore it is more likely that they will have the time and commitment to see a project through from start to finish on schedule. Finally, to manage the problem of undergraduate student schedules, finals, course loads, vacations, and turnover, several rules have been instituted in the SSEL. All students begin as temporary volunteer workers, and only those who prove they have a lasting interest in the undertaking are hired on for academic credit or stipends. Most students therefore stay with the lab longer, reducing turnover. Also, students who are hired for stipends or credit cannot simply drop out of the program when their schedule becomes busy; they are committed for at least a full semester. An effort is made to hire as many students as possible to work through the summer when they are typically undistracted by classwork and final exams. While working, documentation is stressed as a critical component to any successful engineering endeavor. Students are required to submit monthly progress reports, keep logs updated and readily available, disseminate information to other team members through a master email list, and attend meetings and design reviews to diversify knowledge throughout the team. It is the goal of these rules to ensure that there is always more than one student intimately knowledgeable on each subsystem, so that in the event that a student leaves the project, they will not take irreplaceable information with them. These rules and organizational methodologies work together to maintain stability and a feasible schedule on a student-operated project.

K-16 Outreach

The Space Science and Engineering Laboratory attaches a high degree of importance to educating students and the public about satellites and space science, and to that effect, has instituted a number of public outreach educational programs. Due to this previous experience, much of the infrastructure facilitating a public outreach program for a new satellite mission is already in place. For the MEROPE and Maia projects, team members disseminated information to students at the K-12 and college levels, university faculty and visitors in a number of ways. Dozens of public lectures have been given since January 2001, primarily to K-12 students. High school physics classes were visited in Montana and Oregon, public talks were given to pre-elementary school children and their parents, and several middle school groups across the state of Montana enjoyed previous MEROPE and Maia - and currently SpaceBuoy – presentations.

The outreach does not however end with high school; at the college level, members of the SpaceBuoy team have introduced several physics and engineering classes to the opportunities available with the project and have also given introductions to the lab to visiting students from Native American tribal colleges in the state. Lectures about the exciting science and technology aspects of student satellite construction are not only offered by the Space Science and Engineering Laboratory students, but also by the Space Public Outreach Team (SPOT) project operated by the Montana Space Grant Consortium (see http://www.montana.edu/~wwwmsgc/Text/SPOT.html). Students involved with this program present a variety of topics concerning space science and exploration free of charge to interested groups in Montana.

The Space Science and Engineering Laboratory's SpaceBuoy project maintains a student-constructed website containing information about the mission and space science for all levels of browsers (see http://ssel.montana.edu/missions/post.php?post=15&action=edit#). Explanations for the motivation of the project and scientific data are available.

As can be seen, the Space Science and Engineering Laboratory places high value on public outreach and will continue to do so with future satellite projects. The precedent that has been set for giving regular public lectures, school visits, and SPOT programs will remain. Students will continue to improve and fill in the web site and a promotional effort will be undertaken allowing students to come up with an original acronym for Maia, receiving a certificate from the web site to signify that they participated in Montana's second satellite.

Space Operations Center

The space operations of SpaceBuoy are also important. Students will perform tracking, telemetry, and on-orbit operations for SpaceBuoy. It is the goal of SpaceBuoy to involve the amateur radio (Ham) community as much as possible in the operations, data gathering, and design. This relationship with the amateur radio community greatly increases understanding and knowledge about RF communications and communications systems, as well as development of new and interesting technologies for our students.

SpaceBuoy's on-orbit operations can then occur primarily from MSU as well as partner institutions around the country or world. Students have a primary responsibility for assessing the on-orbit performance of the satellite and will publish the results of our experiences in the engineering literature in addition analysis of the scientific data will be carried out by students, and the results published in appropriate peer-reviewed journals.

Archival Publications (published) during reporting period:

None

Changes in Research Objectives:

None

Change in AFOSR Program Manager:

None

Extensions granted or milestones slipped:

None

APPENDIX 1: Annual Progress Report submitted March 18, 2010

ANNUAL PROGRESS REPORT SUMMARY (Year 1)

Grant Title: NanoSat FY09: "Spacebouy: A University Nanosat Space Weather Mission (II)"
Grant #: FA9550-09-1-0076
Reporting period: January 15, 2009 – January 14, 2010

Submitted by Prof. David M. Klumpar
March 18, 2010

Program Manager: Dr. Kent Miller

Annual Accomplishments

Spacebuoy-II will collect data on several ionospheric parameters essential to space weather forecasting from a nanosatellite platform and demonstrate provision of data to the forecasting community within 1.5 hours. During this first year the SpaceBuoy-II mission concept has completed its requirements flowdown from mission statement and objectives to system and subsystem requirements leading to engineering implementation. Instrument confirmation (NRL's CITRIS receiver for Total Electron Content and AFRL's Planar Langmuir Probe, in a dual probe configuration, for in situ plasma density) and interfacing with the spacecraft has been completed. Engineering development is under configuration management control and requirements verification is being tracked. Spacecraft systems are proceeding through development. Structural and thermal analyses and a test and verification plan are in progress. Prototyping of systems (ADCS, antenna deployment, C&DH, and communications) is in progress and technical resource budgets (power, communications link, and mass and volume) are showing comfortable margins. Major project milestones and program reviews have been met: SCR (04/09); SHOT 1 (06/09), a subsystem rocket flight (06/09), PDR (08/09), and Sat Fab (01/10). Our CDR package is nearing completion, and at the end of the reporting period, preparations are underway for our April 20, 2010 site visit CDR.

Archival Publications (published) during reporting period:
None

Changes in Research Objectives:

None

Change in AFOSR Program Manager:

None

Extensions granted or milestones slipped:

None